RECENT ADVANCES IN EXTINGUISHMENT OF BURNING COAL REFUSE BANKS FOR AIR POLLUTION REDUCTION

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INTRODUCTION

THE BURNING REFUSE BANK PROBLEM

A coal refuse bank is an accumulation of rejected material resulting from the mining and preparation of coal. These banks usually contain rock, coal, bonded coal, carbonaceous shale, pyrites and other debris from the mining operations; including possibly, paper, grease containers, rags, timbers and miscellaneous discarded mining supplies and equipment. In some cases, the refuse bank may also be a site where indiscriminate trash and/or garbage from nearby dwellings accumulates which adds to the possibility of combustion.

One of the problems important to the health and safety of the people of the coal producing areas, as well as to overall economic development in the coal regions, is that of burning coal refuse banks or piles. It is estimated there are at least 200 of these burning banks in Pennsylvania at the present time. Many of these burning piles are located in areas remote from urban development, however, many are causing air pollution in built-up areas.

For over 300 years, fires in accumulations of coal refuse and stored coal have been and still are occurring as a result of spontaneous combustion or other means of ignition. Currently, due to state and national regulations on air pollution and smoke control, attention is focused on the burning of discarded coal refuse, produced during the preparation of coal or from selective mining techniques. For many years these unsightly refuse areas were deemed a necessary evil of coal mining regardless of the devaluation of adjacent property, and the particulate matter and noxious sulfurous gases which they release into the atmosphere when burning.

The fate of many of the early refuse banks with respect to spontaneous, accidental, or deliberate combustion is not known. It may be concluded that many did burn, particularly in view of the inclusion of small coal with the spoil discharged to the piles. The large tipple-formed piles were particularly liable to spontaneous combustion. It may be assumed from the many examples of burned out colliery spoil banks which had been formed during the first half of this century that combustion was the rule, rather than the exception in many of the coal fields.

PUBLIC CONCERN

Passage of the Pennsylvania Air Pollution Act required the owner of a mine to employ all practical means to prevent the ignition of the refuse disposal from the mine and to prevent or minimize the emission of smoke and fumes from the refuse. An important exception was that the liability did not extend to deposits of refuse made before the passage of the Act, which at the time, were no longer in use and which were not under the control of the mine owner.

In Pennsylvania prior to 1963, the Department of Mines and Mineral Industries was not authorized by law, nor did it have the funds to attack burning bank fires. A few brief efforts had been made at extinguishment in the past, using the Governor's Emergency Fund or Civil Defense Funds. In 1963, legislation was passed which authorized funds to begin extinguishment of these bank fires. During 1964, two fires were extinguished with funds provided by the State Legislature. Through research and demonstration projects, varied techniques have been attempted in an effort to seek more efficient and less costly methods to extinguish burning refuse banks.

As far as existing non burning abandoned refuse banks are concerned, a continuous surveillance or patrol system is required, in order to promptly initiate abatement work as soon as a fire occupies a portion of a bank.

OCCURRENCE AND CAUSES

A 1963 survey conducted by the U.S. Bureau of Mines indicated that there are more than 495 refuse piles on fire in the United States. This report which is approximately six years old, is of necessity, inaccurate at the present time because new fires are constantly starting and through government and private efforts, fires are being extinguished and some piles are burned out.

The main cause of these difficulties, apart from the high carbonaceous content of piles, is said to be the tippler form of pile construction. This form of construction encourages the segregation of the larger pieces of spoil to the toe of the pile which allows the easy passage of air into the center. The rising bedding planes and the lack of consolidation allow internal convection currents to flow and the steep faces encourage penetration by the wind. The steep faces increase the difficulties of controlling any combustion which starts in particular, it is almost impossible to blanket the faces of these piles with clays, etc.

At the present time, approximately 25% of the run-of-mine coal reports to the refuse disposal area. Coal refuse material, when stockpiled at random, reaches ignition temperatures readily. The resulting combustion occurs in many different degrees from smoldering to active burning. Atmospheric conditions have a marked influence on this burning. Heat is liberated continuously, although this is not visible under warm, clear conditions. Cool, damp atmospheric conditions produce excessive vapor and smoke and together with the obnoxious gases high in hydrogen sulfide and sulfur dioxide produce an air pollution problem in the immediate vicinity and down wind from the refuse piles.

Modern coal mining practices and coal cleaning facilities increased the proportion of waste handled. Mechanical mining machines used in most anthracite and bituminous mines today are not selective and mine a considerable amount of rock and other non carbonaceous material which reports to the refuse pile after having passed through the preparation plant.

Ignition of a refuse bank can be initiated in several ways. A recent U.S. Bureau of Mines report outlines the following possible sources of combustion:

1. Spontaneous ignition:
    a. Sufficient air must enter the refuse dump to oxidize the coal and other combustible materials.
    b. Air must be insufficient in quantity to carry away the heat generated during the oxidation, thus permitting the heat to accumulate.

2. Careless burning of trash on or near the bank.

3. Forest fires.

4. Camp fires left burning.

5. Intentional ignition to create residue which may be used for road base materials.

BASES OF EXTINGUISHMENT METHODS

Coal and the carbonaceous minerals which form the major component of most refuse begin to oxidize as soon as they are exposed to the atmosphere in the course of mining. When small quantities of refuse are involved, the heat evolved will be dissipated, but when large masses such as banks are exposed to the atmosphere, thermal chain reactions may develop and active combustion may appear.

Any attempt at extinguishing a burning refuse bank and the elimination of resulting air pollution, must be based on the usual time honored extinguishment theories. The usual components of any combustion process must be eliminated through one technique or another. Air may be kept away from the carbonaceous material in such a way that no ignition is possible. A refuse bank may be re-cleaned in order to eliminate the fuel and lower the possibility of combustion. Cooling processes may be applied to lower the kindling temperature below the threshold for ignition. The ignition temperatures of Pennsylvania bituminous coals range from 327° to 420°C. The ignition temperatures of Pennsylvania anthracite range from 450° to 510°C. Pyrite and slate mixtures found in anthracite have been found to ignite at 417°C. Waste materials from mining operations, including powder boxes and timber will ignite at temperatures as low as 219°C. Most efforts aimed at extinguishing refuse bank fires have dealt with one of the three key ingredients of combustion - removal of oxygen, lowering of kindling temperature, or removal of fuel.

REFUSE BANK EXTINGUISHMENT

PREVIOUS WORK

During the period October 1, 1949 to May 31, 1951, a research project on mine refuse fires was conducted by the staff of the Department of Mineral Preparation at the Pennsylvania State University under the direction of Dr. H. B. Charmbury. The project was sponsored jointly by the Pennsylvania Department of Mines and Mineral Industries, the Central Pennsylvania Coal Producers Association, and the Western Pennsylvania Coal Operators Association. The research was concerned with an investigation to control mine refuse fires. Over 350 coal companies were contacted regarding the problem and data were obtained on over 800 piles. At only 81 of the locations were special efforts being made to pile the refuse to minimize possible ignition. These methods included layer piling, layer piling with clay, sealing the pile with clay and fly ash, digging out and backfilling, and using trenches for storage. Some efforts were being made to extinguish burning piles. These included the use of water and the use of bulldozers to isolate the burning section. Neither of these methods was entirely successful.

Many methods such as flooding, blanketing, slurry injection, compacting, loading out, and sealing have been attempted in the past to control bank fires. A review of the pertinent literature regarding spontaneous combustion, refuse bank extinguishment efforts, coal - refuse storage, and related topics will be found in the attached bibliography (Appendix A).

RECENT WORK

Work has been conducted with funds made available by the Legislature of the Commonwealth of Pennsylvania and in certain instances, matched with Federal funds from the National Air Pollution Control Administration of the U.S. Department of Health, Education and Welfare. Demonstration projects have been devoted to finding newer and more practical methods of extinguishing burning refuse banks. In each of the various extinguishment techniques, the overall program followed the procedure outlined below:

1. Initial engineering and planning of the work and investigating possible problems and solutions.

2. Arrangements with qualified contracting firms to do the physical work.

3. Actual performance of the prescribed extinguishment program by the contracting firm with on the job consultation and surveillance by representatives of the Pennsylvania Department of Mines and Mineral Industries.

4. Evaluation of the extinguishment project by the project contractor and departmental staff in order to evaluate the extinguishment technique.

In most cases, the subject bank was chosen on the basis of finding areas where a demonstration project would serve the dual purpose of demonstrating and evaluting a new or modified technique and concurrently abating pollution which was creating a nuisance in a nearby community. Such refuse bank fires were located in both the Pennsylvania Anthracite and Bituminous fields. The contractor in each case was under obligation to secure the necessary permits from the State regulatory agency, (the Air Pollution Commission of the Pennsylvania Department of Health), and any required easements from private property owners.

In many of the demonstration projects, the approach taken was suggested by the Department's representative. However, in a few cases, the demonstration project was based on a plan or procedure presented to the Department by an engineering and/or contracting firm. The methods explored are listed on the following pages.

Accelerated Combustion and Quenching: A research project was conducted in the anthracite region involving the lifting of burning refuse material by a dragline and dropping the hot material through an air drop of 50 to 100 feet into a water filled lagoon. In the process of dropping the hot refuse material through the air, a considerable amount of combustible material was burned off, in some cases with a flash - explosion, while allowing the hot material to fall into a water filled lagoon. Following the water quench, another dragline lifted the quenched material out of the lagoon floor and placed the extinguished material to the rear of the operating equipment where bulldozers spread the material and compacted it into a tight, dense fill material. The work performed in this technique appeared to successfully extinguish the material and place it in a form in such a way that it would not further ignite. One shortcoming of the above mentioned technique, is the concurrent evolution of particulate matter during the air drop of the burning refuse. It may be possible that the technique described above may lend itself to extinguishment of refuse bank fires in areas remote from populated areas. This technique is applicable to large refuse banks.

Isolation: If the bank fire is in a very early stage of combustion, the burning area may be isolated from the remainder of the burning bank by ditches which cut completely through the bank to the bare soil underlying the bank. The isolated hot material can then be quenched with water or moved to an area and mixed with cold incombustible material. In some cases, the trench or ditch which is so created is lined with clay or earth to minimize the entrace of air into the porous bank material.

Foam Covering: In this project, a polyurethane foam was applied to a terraced-contoured refuse bank. The bank was contoured into a number of equal steps approximately 50 to 70 feet high and with a one to one slope between the roadbed and the rising slope to the next level. After shaping the pile, water sprays were applied to cool the surface material. Following such cooling, polyurethane foam was applied to all sidewall and roadbed surfaces. The pile temperature has decreased and continues to decrease over a period of 18 months following the application of the foam cover. In certain areas, excessive temperatures caused a charring of the foam and it was necessary to remove and rebuild a foam coating following a deep water spray and cooling of the localized "hot spot." It is felt that this technique lends itself to small refuse banks that are not excessively hot. It should be noted that certain shortcomings are obvious in this technique and this includes the possible damage to the coating surface by children or vandals and that a pile extinguished via this smothering method will need constant maintenance until the entire pile has cooled beyond the kindling temperature. In a subsequent project, based on a similar foam covering principle, further work is being done to reduce the thickness of the foam cover in order to reduce costs and additional steps are being taken to prevent surface degradation by sunlight through the use of paints applied to the foam surface. Fiberglass and/or other strengthing materials may be laid on the horizontal traveling surfaces to reinforce these areas. Additionally, surface treating materials will be applied in order to reduce surface temperatures and provide a firm non-absorptive base for foam application.

Vermiculite and Sodium Bicarbonate Injection and Coating: This project aims at filling voids and reducing oxygen entry, as well as, sealing the surface. A mixture of vermiculite, sodium bicarbonate, limestone dust and resin, has been injected into and applied on to a shaped refuse bank. Some promise is shown by this method due to the expansion of vermiculite with the application of heat. The technique has not been completely evaluated. Preliminary results, however, would indicate that void filling with such materials is beneficial for a short period of time, but may, in fact, be too costly to justify the end results. The materials used, do not form a tight seal on the surface of the bank which is sufficient to exclude oxygen from the interior of the bank. Further work using this technique may be done, however additional emphasis would be placed on surface sealing in addition to the injection of these materials.

Injection of Fine Mineral Matter: Fly ash, coal silt, and rock dust, have been injected through drilled holes in the periphery of a burning refuse bank in order to fill voids and reduce air intrusion. This technique appears to be relatively successful, but again, the process of void filling must be followed by adequate surface treatment in order to prevent erosion and gully formation on the refuse bank surface. Heavy rain may often lead to the wash-out of the injected fines and the renewed porosity and oxidation problems along the sides of the eroded gully. The availability of such mineral materials adjacent to refuse banks and from the fine coal cleaning circuits of a normal preparation plant does offer considerable promise to this technique, especially if it were coupled with some relatively inexpensive surface sealing techniques.

Mine Drainage Sludge Injection: A project is now in progress in which acid mine drainage containing a high amount of iron and calcium salts is neutralized and the resulting iron hydroxide and gypsum sludge is injected into the burning refuse bank. The sludge of iron hyroxide and gypsum mixture forms a tight impermeable cake or crust on the pile and appears to merit further consideration. The small project which has been initiated has not been concluded, but present evidence would indicate that there is considerable merit in this procedure and is a relatively low cost disposal site for the troublesome treatment plant sludge and could concurrently help with refuse bank extinguishment efforts.

The Use of Anti-Oxidants: The discovery of a cheap reagent which could be applied to refuse to retard the rate of oxidation of the exposed pyrite would be an excellent solution to this and several allied problems. Unfortunately despite continued research, the prospects of finding such a reagent is still going on.

Laboratory experiments with chromates, phosphates, and sodium hydroxide were reported to be unsuccessful and a full scale test in which liquid ammonia was applied to abandoned mine refuse in an attempt to control the oxidation of the pyrite had also been unsuccessful. Tests involving up to 1 per cent of limestone powder added to small coal stock piles did retard the acidity initially, but after six months, the effect disappeared, even though most of the limestone had not been consumed. For the time being, it must be concluded that no specific reagents for the retardation of the rate of weathering of pyrite are known.

However, the use of oxidation inhibitors is being reviewed under a project which is continuing in Pennsylvania. A candidate group of inexpensive organic and inorganic anti-oxidants and flame retardants was evaluated by a chemical company. Small prototype piles or firing chambers were constructed by the firm and various concentrations of candidate materials were added in the solid and/or solution form and the degree of ignition retardation was measured. The product which was found to be best has been applied in an aqueous solution to a burning refuse bank. Four areas have been laid out on this bank in order to establish the degree of success attainable through the above application. A control strip involving no treatment was laid out, a similar area was sprayed with only water, another area was sprayed with water and a surfactant, and the test area was sprayed with a water solution containing the anti-oxidant. Results to date indicate that the retardant has some desirable properties and the desired effect on the pile. H wever, applications must be at a much higher dose rate than originally anticipated.

Saturation Through Serpentine Canals: A refuse bank located in the anthracite field was covered with an array of interconnected serpentine canals or troughs, in an order to allow water maximum time to percolate through the pile. It is necessary to apply water through such a remotely located canal system so that personnel will not be in danger by secondary explosions or evolution of clouds of gases and/or steam at the point of water and refuse contact. The interconnected array of canals was constructed by bulldozers. The operators were equipped with oxygen breathing apparatus. Following the construction of the interconnected canals, water was pumped to the highest point in the canal system and allowed to flow in a "zig zag" pattern down the side of the bank. While this water treatment and cooling procedure was proceeding, other equipment was preparing another canal system in another part of the pile. After several months of canal construction and wetting, the technique was abandoned. The procedure did not allow sufficient percolation of water from the surface to the area beneath the superficial surface crust. Only percolation to the depth of two to three feet was noted.

Ponding Technique: A series of adjoining lagoons was constructed on the top of a relatively flat refuse pile which had been built across a valley bottom. Retaining walls were constructed around the perimeter of the refuse bank area, subdividing the surface into a series of level discrete areas or "rice paddys." Upon construction and in sequence, water was admitted through a series of canals into the flat impoundment areas. Evolutions of vapors and steam were immediately evident. Pools of water were retained on the top of such flooded areas for periods extending to a period of several weeks. Flooding may be hazardous inasmuch as explosions have been known to occur when a large quantity of water was rushed onto the fire area. After several weeks of soaking, an area would be allowed to drain and experimental cuts were made into the lagoon floor. In some cases, it was found even after several weeks of standing under several feet of water, penetration of the water into the refuse material was only two to three feet and temperatures in excess of 400° were found only several yards beneath the water. Work following this procedure has been continued and in spite of the necessity to continue to maintain a water cap on such ponded areas for an extended period of time, the technique is considered to be of relatively low cost per unit refuse extinguished.

Cooling and Dilution: This method involves the preliminary cooling of the refuse pile by remote application of a water spray from multiple nozzles. The cooled refuse is then mixed in a one to one volume proportion with soil and/or burned out coal refuse from a nearby borrow area. The mixing of extinguished but warm, damp coal refuse and the inert material is carried out by the bulldozer operator. The material is then laid down in a new portion of the tract and compacted by heavy equipment. Where cooling and diluting material is available and sufficient land is available, the above technique appears to be most promising and one of the least costly on a cost per cubic yard extinguished basis.

Blanketing With Clay and Cement Waste: A bank was covered with a mantle of clay along all sidewalls following conventional practice which has been performed many times with mixed success by the coal industry. (Experience has shown that complete clay covering of a refuse bank often leads to the formation of a "baked" clay seal which in due course, cracks and allows the re-entry of air and the re-firing of the cooling refuse bank.) In the technique attempted by the Pennsylvania Department of Mines, sidewalls of the refuse bank were covered with clay and the clay was compacted. The open top was covered with a layer of two to three feet of cement kiln waste dust. This dust which contains a certain amount of portland cement is a waste product from the nearby cement industry. The material was delivered by tank truck and placed on the flat top surface of the refuse bank. The surface of the cement dust layer was sprayed in order to form a crust to the depth of one to two inches. The dust beneath the surface crust remains fluid and filters down into cracks and fissures in the bank as they may occur. This technique appears to be successful and may be applicable to small piles that are adjacent to or near the cement industry.

Blanketing - Quarry Wastes: This technique involves shaping of a refuse pile followed by the application of minus 1/2"limestone quarry wastes to the top and sides as a sealant and the revegetation of the pile by hydroseeding. The compaction of the pile followed by the limestone covering of the sides and top appears to be rather successful. The evolution of carbon dioxide at the site of any hot spots may be useful in extinguishing the fire in the bank. The use of quarry wastes again carries the dual benefit of finding a useful outlet for this mining wastes material, concurrent with the blanketing and fire extinguishment purpose. Any run-off, following precipitation, from such a quarry waste covered bank would be of an alkaline nature. Due to the soil characteristics, an experimental planting has been done on the sidewalls of such a treated bank and a substantial stand of grass has established itself on this bank.

Use of Explosives Followed by Quenching: Many large refuse banks do not lend themselves to water quenching due to the previously mentioned fast run-off of water which is applied to the surface. A surface crust of impenetrable ceramic like clinker material does not allow the penetration of quenching water. In order to penetrate such a partially burned bank, the Department of Mines and Mineral Industies has placed horizontal boreholes into the burning area of the bank and placed heat insensitive explosives into the boreholes. The explosives are detonated and the broken up material is then quenched with water jets. This material has been used in an urban pile with a high degree of technical success and with reasonable economics. This technique is considered to be among one of the better procedures for application on piles which had heavy crusts of partially burned out material.

Hydraulic Jets: Projects conducted by the U. S. Bureau of Mines and the Pennsylvania Department of Mines have involved the application of "hydraulic giants" or high pressure or high velocity water cannons similar to those used in the placer mining industry. The application of high velocity streams of water undermines larger portions of the bank as well as quenching the bank material. The quenched material will fall or roll into a lagoon from which it is lifted by draglines. The quenched material is removed from the lagoon and placed behind the hydraulic jets and compacted by bulldozers. The effect of this technique is to extinguish large volumes of very hot materials while attaining a high degree of safety for operating personnel. In addition to the cooling and quenching action of the water jets, there is a good deal of particle size reduction and degradation which takes place in this material handling technique. When the material is then relayered and compacted by the dragline - dozer combination, the material attains a cement like very dense characteristic which is considered to be virtually incombustible.

Water Sprays Only: The use of water sprays to control combustion in refuse piles has been deprecated by some authorities, but is still practiced. At best, this method can be considered to be only a temporary expedient for temperature and fume control until permanent abatement work can be initiated. Work by the U.S. Bureau of Mines recently and the British National Coal Board, has shown that once water spraying is discontinued, combustion takes place again, often with renewed vigor.

Run off from refuse banks is a problem closely related to the fire problem. The thermal reactions have no direct effect on the quality of the drainage from a bank but the indirect effects may be important. Active combustion may generate sufficient heat to evaporate all water precipitated on the bank so that no drainage appears. Provided that the heat is sufficient, the sulphur acids may be dissipated into the atmosphere as sulphur oxides so that acidic contamination of the drainage will not occur, but if the heat is insufficient, the acidic salts may accumulate in the pile and be washed out after the fire has subsided. On the other hand, if the heat is insufficient to evaporate all the precipitation while the fire is burning, the drainage will have a higher than average risk of becoming acidic due to the enhanced oxidation of pyrite at the elevated temperatures. Water applied to a pile to suppress a fire would probably increase the volume of drainage without any corresponding decrease in the degree of contamination.

CONCLUSION

The work involved in the various projects which have been initiated by the Pennsylvania Department of Mines and Mineral Industries requires the application of tried and proven techniques in combination with unproven theoretical applications of engineering and technology. The extinguishment project must be technically feasible and economically practical. The extinguishment project can not be conducted in such a manner that the emission of dust and fumes create an unwarranted nuisance in the immediate area and in the downwind inhabited areas. The creation of such dust and fumes by the extinguishment operation not only creates atmospheric conditions unfavorable for the residents of the area who are in the downwind direction, but make the operation exceedingly difficult for contractors' employees.

Because of the varied shapes, sizes, and elevations of different banks, various methods of movement and materials handling must be explored and tailored to the conditions at any given bank. The availability or lack of water at the project site, also plays an important role in choosing the particular method which can be applied to a bank. Other facts which are of importance include the size of tract and the proximity of homes to the fire area. The availability of inert or diluting solid material either in the form of an earth borrow pit, or completely burned out refuse, also must be taken into consideration in choosing the method to be applied. The extinguishment of small banks is, of course, more readily accomplished and less expensive than large banks. In addition, techniques which are applicable to large banks do not always work equally well with small banks. For example, it is obvious that the use of a hydraulic jet is not warranted in a pile of only several hundred cubic yards of material. Conversely, foam covering could not readily be applied to a multi-million ton refuse bank.

It should be added that following extinguishment, maintenance is required to protect the private or public investment in the abatement project and to minimize the liklihood of any re-ignition. It is known that extinguished material, after having been cooled with water and rehandled and recompacted, becomes a stable, hard surfaced material which produces no dust or fumes and should be relatively immune to any rekindling. Refuse areas should be maintained and regularly inspected in order that hot spots which might develop could be spotted at once and removed and/or filled with an inert material such as clay or earth. Erosion to surface areas must be prevented as gullying allows air entry into the extinguished bank which might rekindle the fire. Following extinguishment, good insurance against further combustion is to deposit a clay and earth layer on the extinguished bank. The earth material should then be seeded with grass in order to minimize erosion and to consolidate the surface and prevent loss of the protected cover. The earth seal covered with a vegetated growth, while it does not reduce the necessity for maintenance, will reduce the maintenance to a minimum and provides protection against re-ignition and also prevents a more aesthetically appealing view for the community.

It should be noted, that virtually all reports indicate that a technique that is successful on one bank, may not be successful on another bank. Each bank represents an individual problem. The engineer, government agency or other organization who wishes to extinguish a fire, must find a technique which can be tailored to the situation at the given bank. It should also be noted that extinguishment may take years, but control is possible to the extent that the fume problem is reduced by gradual steps.

Although several successful bank extinguishment techniques are presently at hand, we anticipate that continued work in this area will provide worthwhile data and may lead to better and more economical methods for the control of this vexing problem.

BIBLIOGRAPHY

(APPENDIX A)

1. Anonymous, "Fire in Coal Stacks," Steel and Coal 186, No. 4931, (1963).

2. Anonymous, Spoilbanks (Review of reports of the alkali inspector) Colliery Guardian, 187, 215-216 (1953)

3. Anonymous, Colliery Spoil heaps, (Review of special publication of the Society of Chemical Industry on the disposal of industrial waste materials), Colliery Engineering, 33, 336 (1956)

4. ARA Staff Study, Culm Bank Fire Extinguishment Huber, Culm Bank Near Wilkes-Barre, Pennsylvania, U.S. Department of Commerce, Office of Program Development (August, 1965)

5. Auth, G. H., Fuels Combustion Handbook, New York: McGraw-Hill Book Co., Inc., (1951)

6. Badzioch, S., D.R. Gregory and M.A. Field, "Investigation of Temperature Variation of Thermal Conductivity and Thermal Diffusivity of Coal," Fuel 43, No. 4, (1964)

7. Barkley, J.F., "The Storage of Coal," U.S. Bureau of Mines, Information Circular 7235, (1943)

8. Barr, W.M., Combustion of Coal and the Prevention of Smoke. New York: Norman W. Henley Pub. Co., (1913)

9. Bhowmik, J.N., P.N. Mukherjee, and A. Lahiri, "Studies on Oxidation of Coal at Lower Temperatures," Fuel 38, No. 2, (1959)

10. Carr, J., A Particular Treatment of Spoil-Bank Fires in the South Derbyshire Coalfield. Trans. Inst. Min. Eng. (Great Britain), v. 107, 1947-48, pp. 169-184

11. Charmbury, H. B., "Phanton Product - Mine Refuse," Mechanization, May (1958)

12. Committee of the Ministry of Fuel and Power, The Efficient Use of Fuel. Lond: His Majestry's Stationery Office, (1944)

13. Davis, J.D. and J.F. Byrne, "Spontaneous Combustion of Coal," Ind. and Eng. Chem. 17, No. 2 (1925)

14. Davis, J.D. and D.A. Reynolds, "Spontaneous Heating of Coal," U.S. Bureau of Mines, Technical Paper 409, (1928)

15. Dixon, E.F. "A Study for Testing of Hydraulic Methods to Control Dust and Expedite Movement of Burning Bank Material and Evaluate Uses of Extinguished Bank Material," Final Report on Project 02-6-09042, Economic Development Administration, U.S. Department of Commerce, Volume I (1967), Volume II (1968)

16. Elder, J.L., L.D. Schmidt, W.A. Steiner, and J.D. Davis, "Relative Spontaneous Heating Tendencies of Coal," U.S. Bureau of Mines, Technical Paper, 681, (1945)

17. Finney, C.S. and T.S. Spicer, "The Ignitibility of Bituminous Coal," Coal Research Board of the Commonwealth of Pennsylvania, Special Research Report 9, (1960)

18. Garcia, M.T., "Spontaneous Combustion of Coal," Ion 14, (1954), Chemical Abstracts 2834(3),(1954)

19. Graham, J.I., "Pyrites and Cause of Spontaneous Combustion in Coal Mines," Trans. Inst. Min. Engrs., London 67, (1923-1924)

20. Greensmith, J.V. 1957/58, The Dirt problem in British coal mines with particular reference to the North Eastern Division, Trans. Inst. Min. Eng. 117, 327-348

21. Hall, Ernst P., and William L. Nelson. A Proposed Seal for Hillside Coal Refuse Piles. Mechanization, v. 17, August, 1953, pp. 119-124

22. Harrington, D. and J.H. East, Jr., "Burning Refuse Dumps at Coal Mines," U.S. Bureau of Mines, Information Circular 7439, (1948)

23. Haslam, R. T. and R.P. Russell, Fuels and Their Combustion. 1st Edition, New York: McGraw-Hill Book Co., Inc. (1926)

24. Hawson, H.G. Problem of Burning Spoilbanks. Iron and Coal Trades Rev., v. 148, Mar. 31, 1944, pp. 489-491

25. Hawson, H.G. Problems of Burning Spoilbanks. Iron and Coal Trades Rev., v. 148, Feb. 18, 1944, pp. 245-247

26. Hebley, H.F. Problem of Controlling Gob Fires. Coal Mine Modernization, 1950 Yearbook, pp. 336-341

27. Hebley, H.F. Control of Gob Pile Fires. Proc. 48th Ann. Meeting, Air Pollution Control Assoc., sec. 26, 1955, pp. 1-7

28. Hodges, D.J., "Spontaneous Combustion," Colliery Guardian 207, No. 5354, (1963)

29. Hodges, D.J. and F.B. Hinsley, "Influence of Moisture on Spontaneous Heating of Coal," Mining Engineer 123, No. 40, (1964)

30. Hood, O.P., "Factors in the Spontaneous Combustion of Coal," U.S. Bureau of Mines, Technical Paper 311, (1922)

31. Hood, O.P., "Spontaneous Combustion of Coal," U.S. Bureau of Mines, Information Circular 7074, (1939)

32. Irons, S.D. "An Evaluation of the Self-Heating Characteristics of Coal Refuse and Their Relationship to Combustible Content" an unpublished Master of Science Thesis, The Pennsylvania State Univerisity (1966)

33. Jones, G.W. and G.S. Scott, "Chemical Considerations Relating to Fires in Anthracite Refuse," U.S. Bureau of Mines, Report of Investigations 3468, (1939)

34. Journal of Air Pollution Control Association. Report of Technical Coordinating Committee for Coal T-4. Pittsburgh, Pa., v. 6, No. 2, pp. 105-110, August, 1956

35. Katz, S.H. and H.C. Porter, "Effects of Moisture on the Spontaneous Heating of Stored Coal," U.S. Bureau of Mines, Technical Paper 172, (1917)

36. Kavrek, P. and P. Takacs, "Determination of the Ignitibility of Coals," Nehezvegyipari Kutato Intezet Kozlemenyei 1 (1959), Chemical Abstracts 6081e, (1960)

37. Kindig, J.K. and H.B. Charmbury, "Investigations on the Operation of the Circular Concentrator for Cleaning Fine Coal," Coal Research Board of the Commonwealth of Pennsylvania, Special Research Report 30, (1962)

38. Leitch, R.D., "Some Information on Extinguishing an Anthracite Refuse Bank Fire Near Mahanoy City, Pa.," U.S. Bureau of Mines, Information Circular 7104, (1940)

39. Long, H.C. and R.J. Wheeler, "Ignition Temperature and Reactivity of Double Screened Coals," The American Society of Mechanical Engineers, Paper 64-WA/FU-1, (1964)

40. Lorenz, W.C. and E.C. Tarpley, "Oxidation of Coal Mine Pyrites," U.S. Bureau of Mines, Report of Investigations 6247, (1963)

41. Lovell, H. L., Mitchell, D.R., Kindig, J.D., and Peters, J.W., "Characteristics of Refuse Bank Materials Which Control Burning and Potential Use", Presented at the Annual Meeting - February 16-20, 1964, New York City, New York, Coal Division, Symposium on Materials Handling, A.I.M.E.

42. Lowry, H.H., Chemistry of Coal Utilization. New York: John Wiley and Sons, Inc., (1945)

43. Lyon, W. A. and Maneval, D.R., The Control of pollution from the coal industry and water quality management in five European countries. Pennsylvania Department of Health, Division of Sanitary Engineering, Publication No. 13 (1966)

44. Maciejasz, Z., "Studies on the Porpensity of Coal to Self-ignition by the Method of Artifical Oxidation," Arch Gormictwa 1, (1956), Chemical Abstracts 10061g, (1957)

45. Ministry of Housing and Local Government, Colliery spoil heaps, Circular No. 26/59, H.M.S.O. (1959)

46. Ministry of Housing and Local Government, New life for dead lands, H.M.S.O., 30 pp, 30 refs., (1963)

47. Ministry of Housing and Local Government, Derelict land, A select list of references, Ministry Library, Bibliography No. 107, 184 refs. (1963)

48. Morgan, P.G., "Liability of Coals to Spontaneous Ignition," Steel and Coal 186, No. 4943, (1963)

49. Myers, James W., Pfeiffer, Joseph J., Murphy, Edwin M and Griffith, Franklin E., "Ignition and Control of Burning of Coal Mine Refuse," U.S. Bureau of Mines, Report of Investigations 6758, (1966)

50. Nelson, William L. and Hall, Ernst P. A proposed sealed circular coal-refuse pile. Mechanization, pp. 85-89, December, (1952)

51. Oreshko, V.F., "Estimation of the Tendency of Coal to Self-Ignition," Zavodskaya Lab 14, (1948), Chemical Abstracts 2754f, (1949)

52. Parr, S.W., "Deterioration and Spontaneous Combustion of Coal," Ind. and Eng. Chem. 17, No. 2, (1925)

53. Parr, S.W., "Effects of Storage Upon the Properties of Coal," University of Illinois, Engineering Experiment Station Bulletin 97, (1917)

54. Parr, S.W. and C.C. Coons, "CO_2 as on Index of the Critical Oxidation Temperature of Coal in Storage," Ind. and Eng. Chem. 17, No. 2, (1925)

55. Parr, S.W. and F.W. Kressman, "The Spontaneous Combustion of Coal with Special Reference to Bituminous Coal to Illinois Type," University of Illinois, Engineering Experiment Station, Bulletin 46, (1910)

56. Porter, H.C. and S.H. Katz, "Effects of Moisture on the Spontaneous Heating of Stored Coal," U.S. Bureau of Mines, Technical Paper 172, (1917)

57. Porter, H.C. and F.K. Orvitz, "Deterioration and Spontaneous Heating of Coal in Storage," U.S. Bureau of Mines, Technical Paper 16, (1912)

58. Porter, H.C. and O. Ralston, "A Study of the Oxidation of Coal," U.S. Bureau of Mines, Technical Paper 65, (1914)

59. Rice, George S. and Hartmann, Irving. Liquid Carbon Dioxide Used to Extinguish a Gob Fire in a German Coal Mine. Bureau of Mines, U.S. Department of the Interior, 1937. (Information Circular 6970)

60. Robinson, C.A. New Mine Fires Are Again Threatening Hocking Valley Coal Fields, Coal Mining, v. 23, No. 12, (1946), pp. 15-17

61. Rohrman, F.A. and J.H. Ludwig, "Sources of Sulfur-Dioxide Pollution," Chemical Engineering Progress 61, No. 9, (1965)

62. Russell, Henry H., "Control of GOB Pile Fires by Injection of Finely Divided Material" Bituminous Coal Research, Inc., (1964)

63. Scott, G.S., "Anthracite Mine Fires-Their Behavior and Control," U.S. Bureau of Mines, Bulletin 455, (1944)

64. Scott, G.S., "Heat Liberated in Low Temperature Oxidation of Anthracite," U.S. Bureau of Mines, Information Circular 7053, (1939)

65. Scott, G.S. and G.W. Jones, "Significance of Low-Temperature Oxidation Products in Anthracite Mine Fire Studies," Ind. and Eng. Chem. 29, No. 7, (1937)

66. Sisler, J.B., T. Fraser, and D.C. Ashmead, "Anthracite Culm and Silt," Commonwealth of Pennsylvania, Topographic and Geologic Survey, Bulletin M12, (1928)

67. Smith, A.F., H.P. Barthe, and S.P. Polack, "Effects of Hydraulic Fluids in Spontaneious Heating of Coal," U.S. Bureau of Mines, Report of Investigations 6221, (1963)

68. Smith, N.R. Fire without smoke, Trans. Inst. Min. Eng. 119, 318-321, (1959/60)

69. Spicer, T.S. and R.W. Borio, "The Effect of Inerts Upon the Ignitibility of Pulverized Bituminous Coal," A.I.M.E. Transactions 226, (1963)

70. Stahl, F.W., "Survey of Burning Coal-Mine Refuse Banks," U.S. Bureau of Mines, Information Circular 8209, (1964)

71. Stoek, H.H., "Fires in Steamship Bunker and Cargo Coal," U.S. Bureau of Mines, Technical Paper 326, (1923)

72. Stoek, H.H., "Safet Storage of Coal," U.S. Bureau of Mines, Technical Paper 235, (1920)

73. Stoek, H.H., "The Storage of Bituminous Coal," University of Illinois Bulletin, Circular No. 6, (1918)

74. Stoek, H.H., C.W. Hippard, and W.D. Langtry, "Bituminous Coal Storage Practice," University of Illinois Bulletin, Bulletin No. 116, (1920)

75. Sussman, V.H. and J.J. Mulhern, "Air Pollution from Coal Refuse Disposal Areas," Air Pollution Control Association Journal 14, No. 7, (1964)

76. Vcelak, V. Changes in Solid Fuels During Prolonged Storage. Institute of Coal Research, Beehovice. Translated by: A. J. Orluk, Pittsburgh, Pennsylvania

77. Veselouiskii, V. S. and E. A. Terpoposova, "Temperature of Ignition of Coal as a Characteristic of Their Tendency Toward Self-Ignition," Izvest. Akad. Navk S.S.S.R. Otdel. Tekh., Navk, (1950), Chemical Abstracts 1227d, (1952)

78. Vologdin, M., E.A. Kamendrouskii, and M.Y. Dobkin, "The Causes of Self-Ignition of Prokopev Coals," Ugol Vostoka 5, No. 10, (1935), Chemical Abstracts 3618(3), (1936)

79. Watkins, G.L. The Stability of colliery spoilbanks, Colliery Engineering 36, 493-497, 11 refs. (1959)

80. Wilkinson, G.G., "Theoretical Considerations Associated with Spontaneous Combustion," Paper to Sheffield University Mining Society and Junior Section of the Midland Institute of Mining Engineers, November 18, 1958.